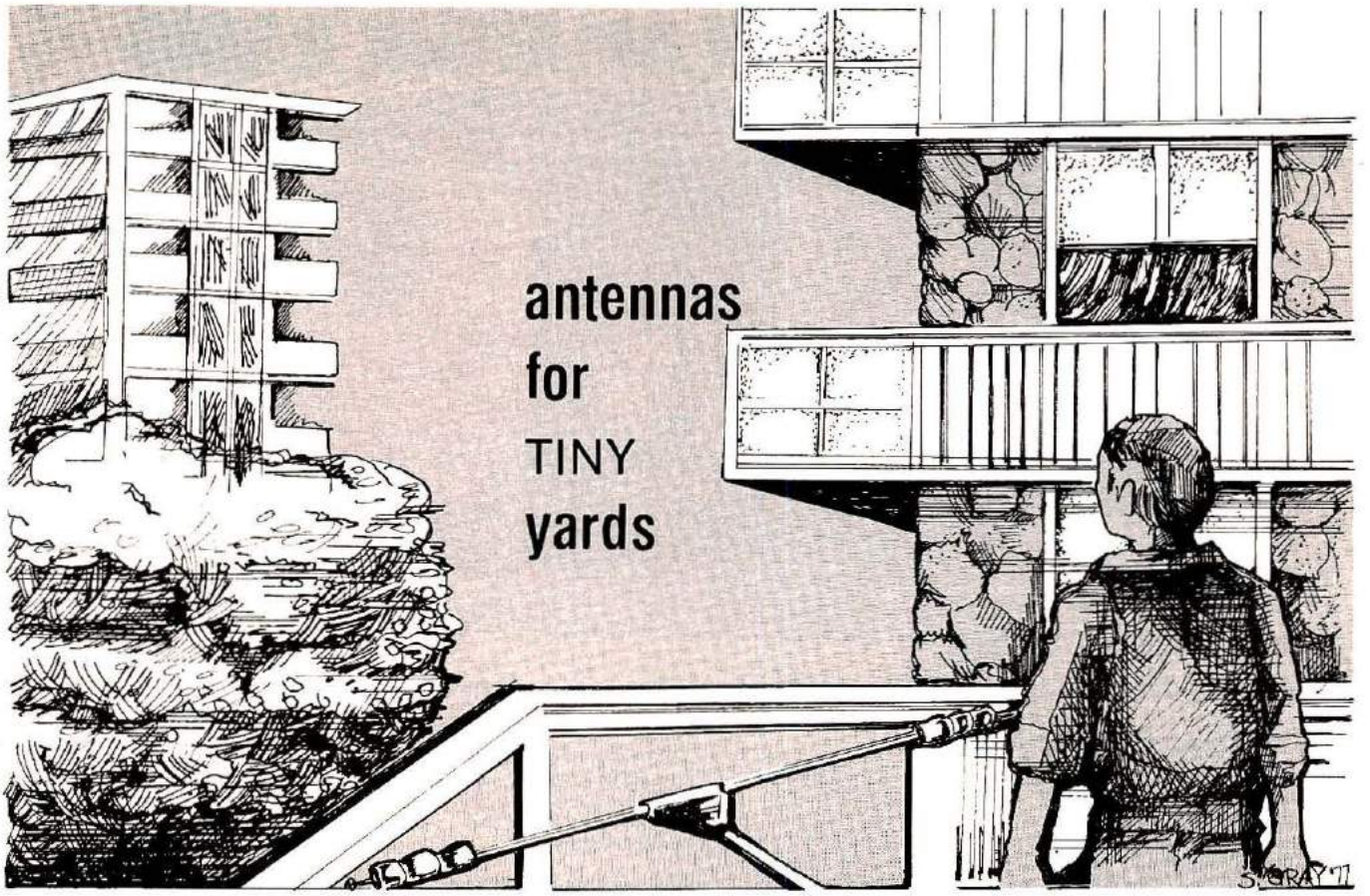


JOSEPH J. CARR, K4IPV

Many people are forced to live with severely limited antenna possibilities. When you are renting an apartment, or living on somebody else's property, then rules other than purely engineering considerations must apply. If an antenna is even permitted in the first place, it must often be a non-permanent and unobtrusive structure. Unfortunately, that can also mean a serious reduction in effectiveness. Of course, we would all like to have a full-sized antenna at optimum height but circumstances force us on occasion to be somewhat more realistic. Now that my wife and I are the proud owners of a little suburban duplex abode, I assumed that those difficulties would be things of the past. Only money, the property layout, and my wife's tastes in outside decor world affect our antenna dreams. Money? Property layout? Aesthetic preferences? It seems that once again it is necessary to drag out some limited-space antenna tricks.

Many article and textbook treatments of limited-space antennas seem to be lacking in the practical sort of "how to..." information that will allow you to implement these techniques. *The ARRL Antenna Book* is a very good source of ideas for limited-space antennas, especially the later editions, but even that book leaves me with more questions than it answers. In this article an attempt is made to distill the knowledge gained through many years of trying antennas that would perform on the high-frequency bands and thereby give you some of the missing "how to..." wisdom.

Standard wisdom

An examination of the standard amateur antenna literature (see bibliography) will reveal a number of designs that have become popular, although some are more popular with writers than with people who actually have to build them. Let's review some of these designs and look at some practical considerations. It is fairly easy to visualize the limited-space problem but what about the matter of limited access? Even in cases where there is plenty of room to put up an antenna there may be several good reasons for not being able to take advantage of the space: the teenager with parents not too sympathetic to unsightly antenna structures, the location of power lines, no ladder, no money to buy one, no place to store it if you bought a ladder, physical disability, or whatever.

The antennas selected for this article, incidentally, were chosen because they are reasonably easy to build and use. I decided that only coaxially fed antennas would

be described because open feeders, despite their unique flexibility, are often a pain in the neck.

The dipole is probably the most common form of simple amateur radio antenna and, in many instances, may be considered a limited-space type. Ideally, the dipole is center fed with 72 to 75-ohm coaxial cable and is stretched between two widely spaced supports, sags little or none, and is relatively high above the ground. But you can almost bet that real-life dipoles never meet these criteria. Most are so un-ideal, in fact, that it rarely matters much at all whether we use 52- or 72-ohm cable as the feedline. There is little chance that the impedance comes anywhere near the theoretical ideal.

Another bit of standard advice is that the dipole must be run in a straight line perpendicular to the direction that you want to transmit or receive. But again, the advice is applicable only to those situations where an ideal antenna can be erected. In your situation you may not be able to approximate the ideal but must be satisfied with something similar to the antenna lay-outs shown in **Fig. 1**. I have used this type of antenna on numerous occasions with some success. The normal half-wave dipole is constructed but is installed with the legs bent to accommodate the geometry of your bedroom or attic space. This type of antenna works best when installed in an upstairs bedroom or the attic, but will give at least moderate results when installed in almost any room except the basement. Of course, in a bedroom installation the technique might be pretty well limited to the upper high-frequency bands (14, 21, and 28 MHz) but in even moderate-sized attics a 7-MHz antenna might be possible.

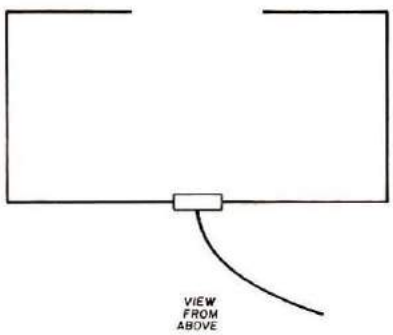


Fig. 1. An antenna for an indoor installation can be bent to fit the space available.

The dipole of **Fig. 2** is for either attic or outdoor installation. In the attic version the horizontal portion might be run along the beam at the peak of the roof and the drooping ends would probably be perpendicular to the main wire. The outside version is suitable for installation where the normal length of a half-wave antenna is greater than the distance between possible support structures. Such antennas are often used on the three lower bands (160, 80, and 40 meters) in city or suburban areas. Insulators are installed at points A and B so that ropes from trees or other supports can be attached.

The antenna layout of **Fig. 3** is unique in that it can be either a side view or a top view. If it is a top view then the bent portions are run horizontally away from the main run. In the side-view version we have a situation where no further horizontal run is possible and the bent portions of the antenna are run up the side of a building or up a tree.

Wire antennas built inside an attic may be supported by TV hardware, specifically the standoff insulators used to support TV transmission line. These are available in either nail or wood-screw configurations that can be fastened directly to the ridge pole at the roof peak. Construction details for the bedroom version are a little more difficult, and are somewhat more subject to

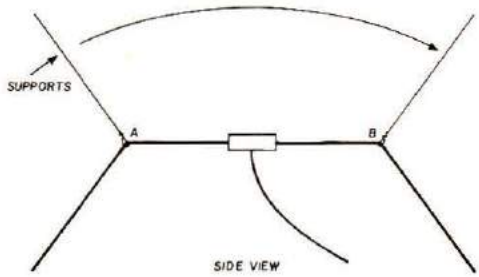


Fig. 2. An outdoor installation in limited space can often be accomplished by using plastic rope as supports. Keep the straight portion of the antenna as long as possible for best results.

family, landlord, or other political problems. Of course, you want the main portion of the antenna as high as possible and that means it should be attached to the ceiling. Other considerations, though, may make it mandatory that it be nailed or stapled to the baseboard. I have used both U-shaped tacks and staples to hold light-weight wire to the ceiling/wall junction. You may find that this is unsightly, but it works. Wire supports that take the place of conduit might be less aggravating to others. These plastic races are adhesive-backed and are relatively easy to install. When building any of the antennas of **Figs. 1, 2,** or **3,** wherever possible, try your best for symmetry. The two halves of the antenna wire (see **Fig. 3**) should be as nearly equal as possible for the given situation. It also helps to make section A as long as possible; minimizing the lengths of the bent portions seems to pay rich dividends. It might be a good idea to use a 1:1 balun transformer at the feedpoint. Several manufacturers offer such devices for sale.

Another alternative limited-space dipole is shown in **Fig. 4**. This antenna is made shorter than normal and is made resonant by placing an inductor in series with each of the two legs. Again, a 1:1 balun is used at the feedpoint. The exact details of this antenna, along with design instructions and a

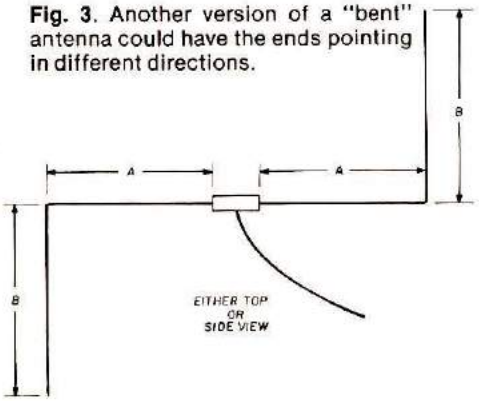


Fig. 3. Another version of a "bent" antenna could have the ends pointing in different directions.

graph, are given on pages 211 and 212 of the *The ARRL Antenna Book*. This antenna is best installed in a straight line away from any obstructions. The coils do not have the mechanical strength to support the wire so a configuration such as that shown in the photograph must be used. This is a ceramic insulator used to support both the coil stock and the two sections of wire. If you are interested in building this type of antenna, look up the article in the *Antenna Book*. Also, you might want to find a way to waterproof the coils. In the one I built, an afternoon rainstorm detuned the coils and rendered them temporarily useless. One amateur has reported success with the use of Lucite tubing with the ends plugged with GE silicone seal.

Fig. 5 shows what is, perhaps, the simplest to build, easiest to install, but most maddening to tune of all antennas used by amateurs: the long wire or Marconi antenna. The principle advantage of this antenna is that it can be installed almost anyplace and doesn't have to be straight. The length designated A in **Fig. 4** should be at least a quarter wavelength long on the lowest band to be covered but even that is not too critical. The long wire is truly a multiband antenna, if you can make it work right. The problem is that a *good* ground, not the kind normally used by most amateurs or SWLs, is absolutely essential. A shortcoming of many articles written about long wire antennas is that they either understress the importance of a good ground or they do not tell you what constitutes a good ground. You must use a ground system such as that discussed in the *Antenna Book* even if it means chemically treating the earth. I have tried using power-line grounds in the shack (not recommended), water pipes, (have you ever tried grounding to a plastic water pipe? Don't!), and even a run of heavy stranded wire to a 6-foot (2m) copper ground rod driven in the earth outside the shack. None of these methods offered much in the way of success. Even the copper wire to the earth was only partially effective because the length of the grounding wire was excessive. Usually, the very factors that preclude the construction of a really decent antenna will also prevent you from being successful with the long wire. If, for example, the ground wire is more than a few feet long, your efforts will seem to be in vain. Often a wide range antenna coupler such as the *Transmatch* or at least an L-section network (**Fig. 6**) is mandatory. All of this tends to lessen the apparent low cost of the long wire. The inductor in the coupler can be either B&W coil stock fitted with an alligator clip and lead to short out unwanted turns or it can be a rotary inductor. The latter is a bit more expensive but is very convenient if the antenna is to cover a wide range of frequencies. The coupling circuit is adjusted for best results: A low swr seen by a transmitter, or loudest signal in your receiver. Many long-wire antennas seem to defy their builder's every attempt to make

For those who can use a transmitter to help in determining the performance of an antenna an swr meter is a valuable tool. Experimenters without transmitters will have to use other methods, such as the grid-dip meter shown here.

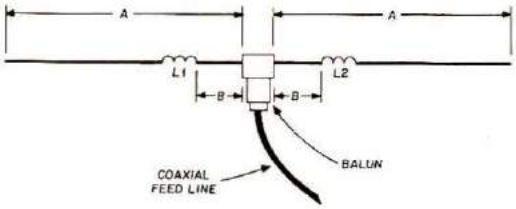


Fig. 4. It is possible to use loading, or compensating, coils to obtain good performance from an antenna that is physically short.

them work. In almost all cases where this is true it is usually traceable to an improper or insufficient ground. Believe me, tuning a long wire and coupler with a poor ground system is a lot like trying to nail Jello to the wall!

Vertical antennas

Fig. 7 shows one solution to the limited-access problem. It is a vertical dipole that has been tried by many people with success. In fact, some insist that it works better than the classic horizontal dipole. The vertical dipole can be built on the ground and then be raised to the attic vent by using a rope which had been previously dropped out the vent slots. A small fishing weight will make it easier to drop the rope to the ground but be careful to keep it from swinging. Even a tiny weight is quite capable of breaking a window pane! If you lack a confederate to help, this type of antenna is a little more trouble to put up but is still very easy, even for a single installer. The only real limit is the height of the attic vent. Antennas up to the 20-meter size (although more realistically 15-meters) are possible in most two-story homes. I put together one such antenna in which the feedpoint was just outside the attic vent and a right-angle run, half inside and half outside the house was used. It wasn't nearly as good as one completely outside the building but it worked well enough at the time. The only problem that might pop up, assuming that you have an attic with a vent in the first place, is the danger of rf burns or shocks from a transmitter to small children who wander into or normally play in the yard. Unfortunately, this is a very real consideration but is not insurmountable.

Not to be overlooked in any article on limited-space antennas is the classic quarter-wavelength vertical or ground-plane antenna. A number of manufacturers offer verticals with traps designed to cover many frequency bands. You can try your hand at building one of your own; an example is shown in **Fig. 8**. The main radiator can be a piece of copper wire if your finances are

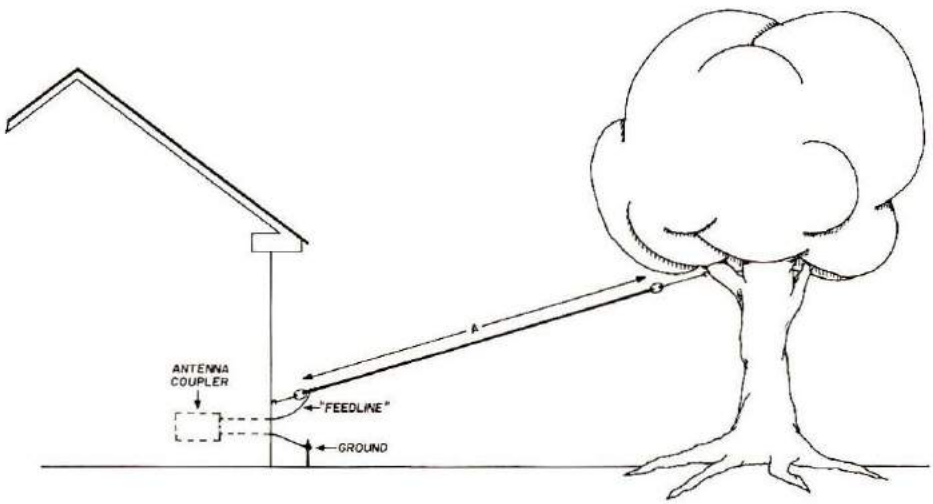
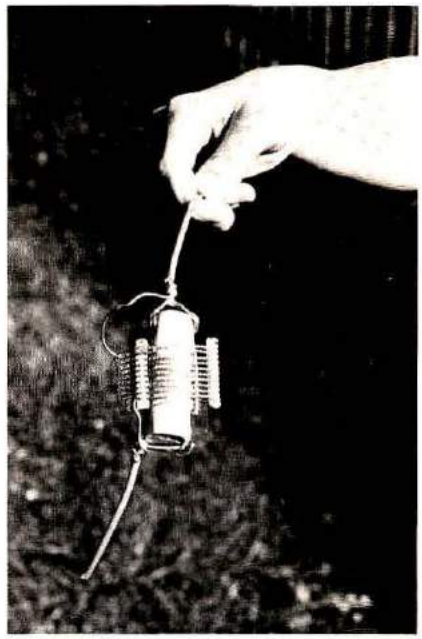


Fig. 5. A long-wire antenna can be erected in many configurations, and often is of a random length. To perform well, this antenna requires a superb ground system and a coupler or matching device.



Compensating inductances for a short antenna (**Fig. 4**) can be made by placing a coil around an insulator.

really at a low ebb, but the system works better if built from aluminum tubing. The larger the tubing, the better the results, or at least so says the "standard wisdom."

It is interesting to note that aluminum tubing is manufactured so that adjacent sizes will fit into one another; the smaller inside the larger. This makes it relatively easy to make a vertical radiator that is strong enough to withstand the rigors of a rooftop installation. Unfortunately, you may have to locate a metal-products distributor or call one of the representatives for the larger aluminum manufacturers in order to find adjacent sizes. Some radio-parts suppliers make it their business to stock popular sizes up to an inch (25mm) or so outside diameter. You will find that most local hardware stores or building-supply houses carry only 1-inch (25mm) and 3/4-inch (19mm) OD tubing and these are *not* suitable for telescoping. Also, they usually stock the six-foot (2m) lengths and it is likely that you will want either eight or ten foot (2.5-3m) sizes. The radials can be made from heavy wire

Table 1. B & W Coil Stock

B & W part number	Diameter inches	(mm)	Turns per inch	Pitch (mm)	Wire size AWG	(mm)	Inductance (μH)*
3025	2.0	(51)	6	(4.0)	12	(2.1)	33.0
3026	2.0	(51)	8	(3.0)	14	(1.6)	59.0
3027	2.0	(51)	10	(2.5)	16	(1.3)	92.0
3029	2.5	(64)	6	(4.0)	12	(2.1)	51.0
3030	2.0	(51)	8	(3.0)	14	(1.6)	90.0
3048	1.25	(32)	6	(4.0)	14	(1.6)	5.0
3049	1.25	(32)	10	(2.5)	18	(1.0)	14.0
3052	1.5	(38)	6	(4.0)	14	(1.6)	7.0
3053	1.5	(38)	8	(3.0)	16	(1.3)	12.5
3054	1.5	(38)	10	(2.5)	18	(1.0)	20.0
3059	1.75	(44)	10	(2.5)	16	(1.3)	26.0
3061	2.0	(51)	4	(6.5)	12	(2.1)	15.0
3063	2.5	(64)	4	(6.5)	12	(2.1)	22.5
3064	3.0	(76)	4	(6.5)	12	(2.1)	32.0

B & W coil stock is manufactured by Barker & Williamson, Canal Street, Bristol, Pennsylvania 19007, and is available from many electronics parts dealers.

*Inductance of entire piece of coil stock. Smaller inductances can be made by cutting the stock.

(no. 14 AWG or 1.6mm is good). You can use TV-rotor wire of the type that has four insulated conductors. You can cut each wire to a quarter wavelength on different bands. The same admonition about the shock or burn hazard still applies. The radials may be angled upwards away from the ground for increased safety. In fact, it is usually the case that these antennas are mounted on the roof or high on the side of the house. Either a length of 2×4 lumber (5×10cm), bolted to the wall, or regular TV-antenna mounting hardware will work well as a support for the vertical antenna. A multiband vertical-antenna system in which the radials are connected in parallel and the vertical portion is resonated by an inductor is shown in **Fig. 9**. Coil-tap-selection can be manual, if it is easy to reach that part of the installation, or it can be done through relays.

Antenna instrumentation

Even with the so-called ideal antennas, it is not too easy to make adjustments without at least some test equipment. Probably the most basic instrument, and one that should be a part of every ham shack, is the swr meter. A great number of swr meters are on the market or can be built from scratch. A popular one is the Heathkit HM-102 which can be assembled as a simple, one-evening project. This particular model also functions as an rf power meter with 0-200 and 0-2000 watt ranges. It is difficult to overstate the advantages of having an swr meter connected while making antenna adjustments. Also used by many experimenters is the dip meter, an example of which is shown in the photograph. This instrument is a vfo which has its resonant tank-circuit inductor mounted externally to the case. This coil is coupled to the antenna or other circuit under inspection and the oscillator frequency is adjusted. When the vfo is tuned to the resonant frequency of the antenna, power will be absorbed from its coil; this causes a dip in the meter reading.

Although the dip meter can be used to check out an antenna system in this manner, it is better to use it as the signal source for an antenna-impedance bridge. I have used the Leader LIM-870A antenna-impedance bridge in some of the experiments made on antennas and have found it to be very helpful. In many cases you really don't care what the natural resonant frequency of an antenna is so long as you know its impedance at the frequency of interest. Unless the impedance is too extreme this will allow you to build a matching transformer. A meter such as the LIM-870A will help you to determine the impedance of the antenna.

For years I have seen the advertisements for the Omega and Palomar noise bridges, but it wasn't until recently that they were tried. I thank K4NFU for putting me on to these instruments because they have paid rich dividends; not something one normally expects from such inexpensive instruments.

Our instrumentation package should, or at least could, include an swr meter, a dip meter, an impedance bridge and a noise bridge. All of these have very definite uses in doping out an antenna system and all are recommended. Also to be included is a receiver, preferably a general-coverage type, and a low-power transmitter.

The frustration quotient for antenna installing can be great if you lack certain essentials. When building an antenna that requires inductors to compensate for the length, you will want several sizes of coil available. It is wise to keep some standard B&W coils in stock. Choose those with few turns per inch, large diameter, and large wire size (smaller AWG numbers). **Table 1** shows some of the B&W type numbers which I have found to be useful in amateur antenna work. If you prefer to use the rotary-inductor approach, then choose one with a maximum inductance in the 15- to 30-μH range. Taps for different bands on non-rating inductors can be either soldered on or they can be made by using alligator clips or coil clips that are sometimes seen in older marine radiotelephones. You will find, though, that any of the clip techniques will be subject to corrosion and will require cleaning from time to time.

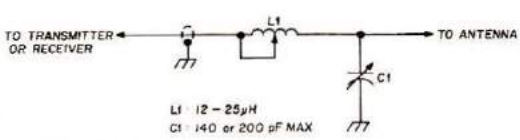


Fig. 6. Matching circuits take on many forms. A very popular one is the L-network shown here, which will cover a wide range because both the inductance and capacitance are variable.

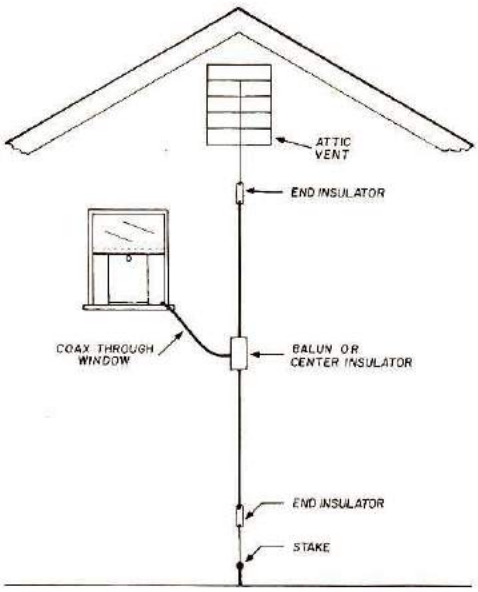


Fig. 7. A simple, yet effective, installation of a vertical antenna can be made by using the features of a house, such as an end wall with a vent or louvre.

One last item that may be desirable when building an antenna is a balun matching transformer. If a relatively standard antenna is contemplated then you can use a standard 1:1 or 4:1 transformer. These are generally low enough in cost to justify their use. In those cases where a really oddball antenna impedance is found then you may want to try one of the non-standard transformer ratios that can be realized using the Amidon toroid Balun kit (about $5.00) or the Amidon T-200-2 core, some enameled wire and the instructions given in several ARRL books including the new *Data Book*.

Adjustments

This phase of any antenna construction project may well be the single most important step to the overall success of the antenna. You are strongly advised to keep detailed records of your trials as you make your experimental adjustments. This will allow you to analyze any problems that develop as you work and will also allow you to duplicate your efforts in the future.

When using an antenna noise bridge or the antenna impedance meter just follow the manufacturer's instructions and act according to the information the instrument gives you. Incidentally, not all low-cost instruments are prone to terrible errors. I have used the Palomar and Omega noise bridges and the Leader impedance bridge on the same project with similar results.

Many amateurs use an swr meter for help in making antenna adjustments because it is the most commonly available instrument. This technique works fine if everything goes according to plan but can lead to difficulty if things begin to go wrong. In that case, you might be better off using one of the other instruments listed above; they might lead you to truth and light where the swr meter could not. Additionally, a license is required to operate a transmitter to provide power for an swr meter.

Your initial adjustment might be to short out an arbitrary number of turns on the inductor and measure the swr or impedance at the desired frequency. Then change the frequency, either up or down band (25 kHz or more), and make another measurement. If the swr is lower downband from the original frequency

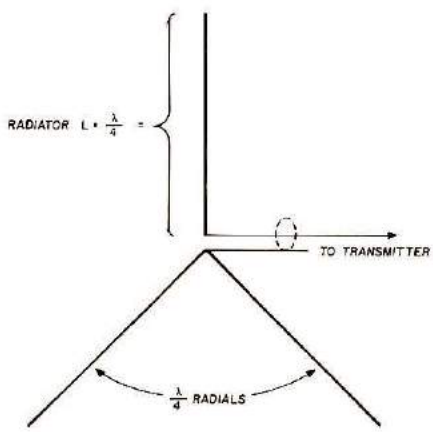
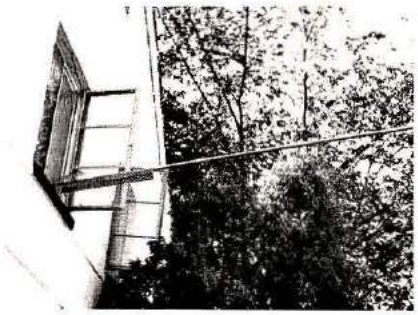


Fig. 8. The classic ground-plane antenna requires radial wires or other well-conducting medium as part of the system. Only two radials are shown here, but performance will increase markedly when more are added.

A plumber's delight with balun and matching coils can be mounted on a piece of board before it is fastened to the end wall of a house.

then the coil has too many turns, but if it is lower upband then the coil has too few turns. Move the tap in the direction indicated by the initial information and measure again. Continue this process, moving the tap a turn or fraction of a turn at a time until the swr is at its minimum point. Your initial selection of turns might be too far off; most people tend toward the optimistic side. In that case you should try picking another "initial" selection of coil turns. On this second attempt try using about half as many turns as you did the first time. If the situation seems to be reversing (see the advantage of keeping written notes?) then split the difference. In a short while you will find the correct placement for the coil taps.

Adjusting previously untuned antennas can be a time consuming and tiring task. This should prompt you to make it as easy on yourself as possible. One of the things which will facilitate the adjustments is to give consideration to the mechanics of the situation. Dipoles, whether vertical or horizontal,



Another answer to the "where to mount it" question is to let the antenna protrude from a window, as my plumber's delight is doing here.

should be fastened at both ends with pulleys and ropes so they may be easily lowered to the ground to be trimmed. You will sometimes find that vertical antennas are easier to rough-in on the ground or leaning up against the wall of the house. At least when the structure is mounted on the roof most of the preliminary work has been completed, leaving only the fine tuning to be done. In some cases the difference in performance between the positions is sufficiently small that it can be ignored.

Two experiments

Everybody "knows" that a dipole should be either all horizontal or all vertical. At my new location neither was possible. The vertical run was interrupted because the only fenced-in wall on the house had the trash cans and gas meter at its base. Additionally, the wall was simply not high enough for a 20-meter dipole. A horizontal dipole was not possible because, in the first place, my new neighbor was not amenable to amateur radio, and secondly, he did not think my antenna, tied to his tree, was entirely in his own best interests. The only tree on my own lot was so small that my portly (fat) frame would not make it safely to a level suitable for dipole anchoring. Hence, the "slipole" (*slanted dipole*) shown in **Fig. 10** was built. A pulley for a flagpole-style rope was installed near the roof line. This made raising and lowering the wire somewhat easier — especially handy since I was working alone. A 1:1 balun was connected at the feedpoint and the Drake MN-4 was used to tune the system. Although I use only low power from an elderly Heath DX-60B transmitter, the system regularly nets good signal reports from Europe and South America. This is not too exciting to the wizened DXer with a high-performance beam, perhaps, but it is sufficient for many hours of enjoyment.

Several articles and a few antenna manufacturers offer what is usually described as a "cliff dwellers special" or something similar. These are window-ledge-mounted antennas that, although they are not super performers, will work for people who simply cannot install a proper antenna. The photographs show a version of this type of antenna: my own "Plumber's Delight." Most similar antennas shown in the literature suffer from the same nail-and-Jello problem as the long wire does because it is seldom easy for anyone who must use such an antenna to get a decent ground. In my version of the antenna, I used an eight-foot (2.5m) piece of 1-inch (25mm) OD aluminum tubing for the radiator and a piece of B&W coil stock to make the thing resonant. The grounding, or ground plane, is taken care of by using radials in a manner similar to that of the full-length vertical antenna. One advantage of these radials is that they can be run to almost any support, even if it is necessary that they be bent. It is best to keep them at least 45° from the radiator. WB4ZOH has used a similar system in which an antenna designed for mobile use is mounted on an apartment-house balcony and a rotor-cable radial system was tacked along the baseboard inside the apartment. Bandchanging is possible either by adjusting the loading coil or by changing the resonator. **Fig. 11** shows the swr plotted for both the slipole and the plumber's delight on 20-meters. In both cases, the swr seen by the transmitter was reduced to very nearly 1:1 by the Drake MN-4 antenna coupler. A W2AU balun (1:1) was used in the final version of this antenna.

The last offering to be made here is the two-band version of the plumber's delight that I erected on the cinder-block side of the house. Radials form the ground-plane system because the antenna is too high to be properly grounded through a wire. Incidentally, a frequent mistake made by builders of vertical antennas is that they use too few radials. A good rule of thumb, up to the point of being ridiculous, is the

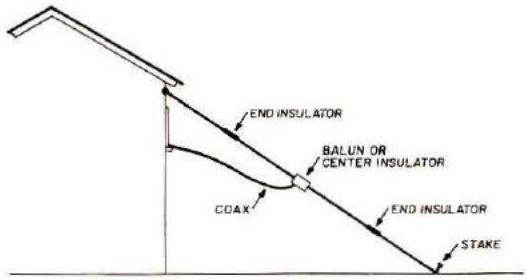


Fig. 10. A "slipole" (*slanted dipole*) antenna should work well, and may be the only answer if your house has metal siding.

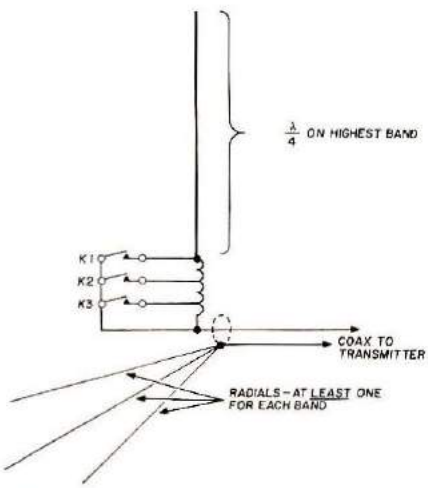
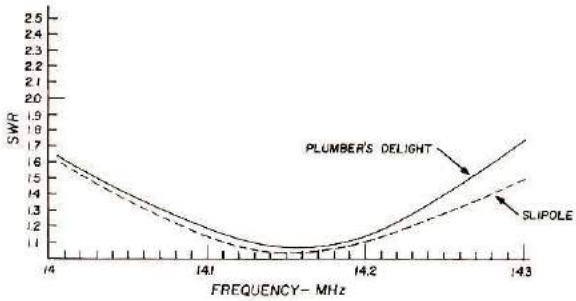


Fig. 9. A vertical or ground-plane antenna can be made to work over a wide range of frequencies by using a tapped coil to change the resonance point.

Fig. 11. An example of plotting the performance of an antenna is this swr vs frequency graph of two antennas described in the text.



"more the better." At least two radials per band is normally the minimum acceptable arrangement. In most instances where someone obtains poor results from a vertical antenna mounted above the ground, the trouble can be traced to too few, or inappropriately designed, radials. The coil stock used for both antennas is B&W 3063. The relay might be a little hard to obtain. I work in medical electronics and was able to salvage it from some defective equipment. It is a Torr model TMR-10 vacuum relay. Several similar relays have been seen recently in the surplus advertisements and at a few hamfests. The original tuning was done when the antenna was on the ground and only minor adjustments were needed when the mounting was completed. This makes it easier for a 300 pounder like me to get the antenna up and working (I don't like ladders).

A question that is often asked is "Will these antennas work as well as a high and clear dipole?" The answer, in a word, is *no*. In most cases they do not work as well as a good dipole or vertical. But it is not my purpose to light cigarettes in Asia with my signal but rather to work stateside stations and whatever DX could be picked off without too much frustration. My initial goal was to get on the air by any means! For a parting shot I would like to officially, humbly, and publicly issue thanks to K4NFU, WB4ZOH, and WA4EPI.

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Glossary of Terms

Balun is a device that will provide a transition between an unbalanced (to ground) line such as coaxial cable, and a balanced line or antenna such as twin-lead or a dipole.

Dipole is a balanced antenna, usually (but not necessarily) one-half wave in length. As commonly built it consists of two equal lengths of wire placed end-to-end with some form of transmission line connected at the juncture.

Ground plane is commonly used to describe a type of antenna that has a system of radial wires mounted adjacent to the feedpoint of a one-quarter wavelength antenna.

Noise bridge is a test instrument that applies a wide-band (noise) type of signal to the circuit being checked, as opposed to a single-frequency (carrier) that more precise instruments require. The most common use is to obtain a measurement of the impedance characteristic of antennas or feedlines.

Radiator is the active portion of an antenna system. Although the term relates to a transmitting antenna, it is proper in a receiving system as well.

SWR refers to *S*tanding *W*ave *R*atio, also *V*oltage *S*tanding *W*ave *R*atio (VSWR). The ratio between the energy being transmitted toward the antenna (or load) and that portion of the energy being reflected back toward the source.

SWR bridge is also called SWR Meter, which is more nearly correct because very few are a true bridge type of instrument. In essence, it is an rf detector that samples both the energy going toward the antenna (load) and the energy reflected back. The indicator may be calibrated so that either a direct comparison of power levels or an indication of ratio is possible.

Transmatch is a device that uses a combination of variable capacitors and inductors to provide a means of matching between unequal impedances. Most often used between a low-impedance transmission line and a high-impedance line or antenna.

VFO means *V*ariable *F*requency *O*scillator: The tuning control of most transmitters or receivers. Can be used to describe almost any oscillator that is not fixed (crystal-controlled) in frequency, especially those that have a connection to a dial or knob for adjustment.

$\lambda/4$ is a symbol representing one quarter wavelength. The Greek letter lambda (λ) is used to represent one wavelength at the frequency of interest. Thus, λ divided by a number or λ multiplied by a number can be used to represent fractions or multiples of a wavelength.